Effects of RAM exposure on a Low Earth Orbit BroadBand Radiometer (BBR): CERES experience and implications for EarthCARE

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1. INTRODUCTION

Cloud's and the Earth's Radiant Energy System (CERES, Wielicki 1996) is an investigation into the role of clouds and radiation in the Earth's climate system. Each CERES instrument (see Fig 1) has three broadband radiometric channels: the shortwave (SW 0.3 - 5μm), total (0.3 - >100μm), and window (8 - 12μm). Four CERES scanning thermistor bolometer instruments are currently operational in sun-synchronous, near polar orbits. Flight model 1 (FM1) and 2 (FM2) are aboard the Earth Observing System (EOS) Terra satellite (Dec 1999 launch) and FM3 and FM4 are aboard the EOS Aqua satellite (May 2002 launch). These instruments measure the Earth Radiation Budget (ERB) parameters of SW and Longwave (LW) outgoing flux from the Earth, which are vital for use in climate model validation (the LW radiance is obtained by subtraction of the SW channel signal from that of the total).

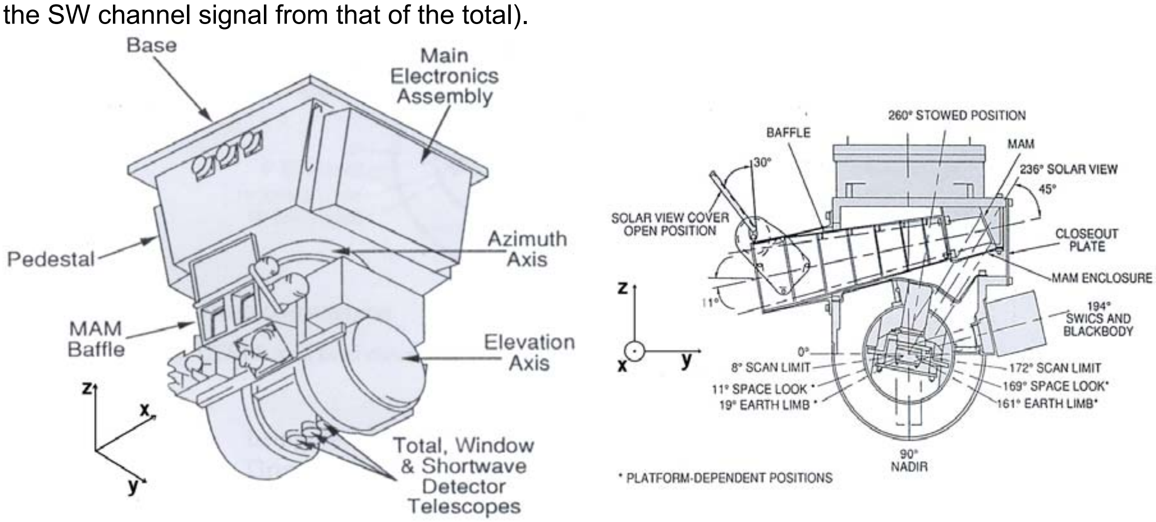

Fig 1. The CERES instrument.

A primary objective of the CERES mission was to develop new and sophisticated Angular Dependency Models (ADMs, Green 1996) which are required to convert measurements of broadband radiance into that of outgoing flux. Their development was achieved by operating one of the two CERES instruments on each EOS platform in Rotating Azimuth Plane (RAPs) mode,

allowing multiple measurements of the same Earth scene with a multitude of viewing geometries. However, by mid 2005 it became clear that the RAPs instrument was subject to significant SW optical degradation, occurring mostly in the UV region (Fig 4(c)) and hence not detectable by internal calibrations using on-board tungsten lamps (Matthews 2005). It was then determined that this degradation, called ‘spectral darkening’, was primarily caused as the RAPs instrument scan plane was rotated in azimuth, exposing its telescope to the ‘RAM’ direction of travel (Fig 3(a) & (b)). Typically it was found that in the early CERES mission, a RAM exposed instrument’s SW response dropped at a rate greater than 1% per year compared to a counterpart operating in cross-track mode (Fig 3(c)). This therefore has serious implications in the design of future broadband LEO missions such as EarthCARE, with broadband channels intended to view in the forward, or RAM direction of travel (Fig 5).

2. IN-FLIGHT SPECTRAL DARKENING OF OPTICS

The Long Duration Exposure Facility (LDEF, Clark 1978) returned an ERB instrument from orbit via the shuttle. This showed how in-flight contamination can significantly lower the response of broadband optics to UV radiance, with very little change to visible or near IR response (Fig 2(a)). This optical degradation, or spectral darkening is also apparent on other Earth observing missions such as the Global Ozone Monitoring Experiment (GOME, Hahne et al 1993) whose UV narrowband channels showed the greatest and most rapid on-orbit degradation (Fig 2(b)). More specifically, the LDEF experiment showed how atomic oxygen in low earth orbit acts

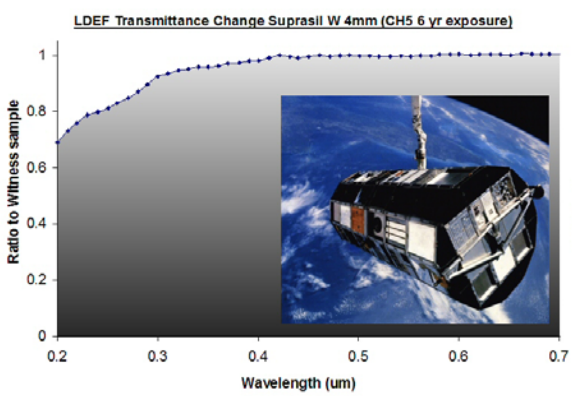

Fig 2(a). LDEF post orbital retrieval measured change in ERB radiometer SW response due to in-flight contamination.

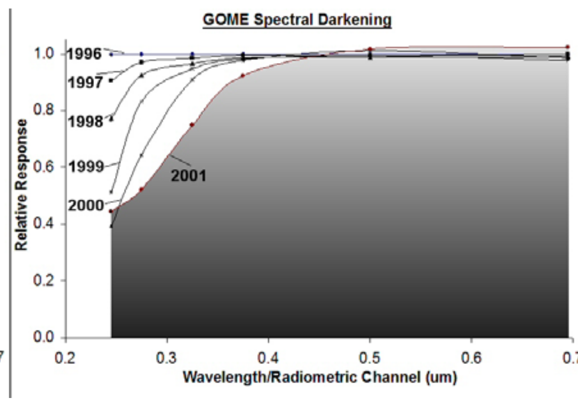

Fig 2(b). Time evolution of GOME narrowband channel response.

to remove and mobilize optical coatings to arrive at other surfaces on the same spacecraft. Earth scattered UV can then fix the contaminant to its new surface, where continued exposure to SW radiance enhances polymerization of contaminant molecules into absorbing chains (Fig 3(b)).

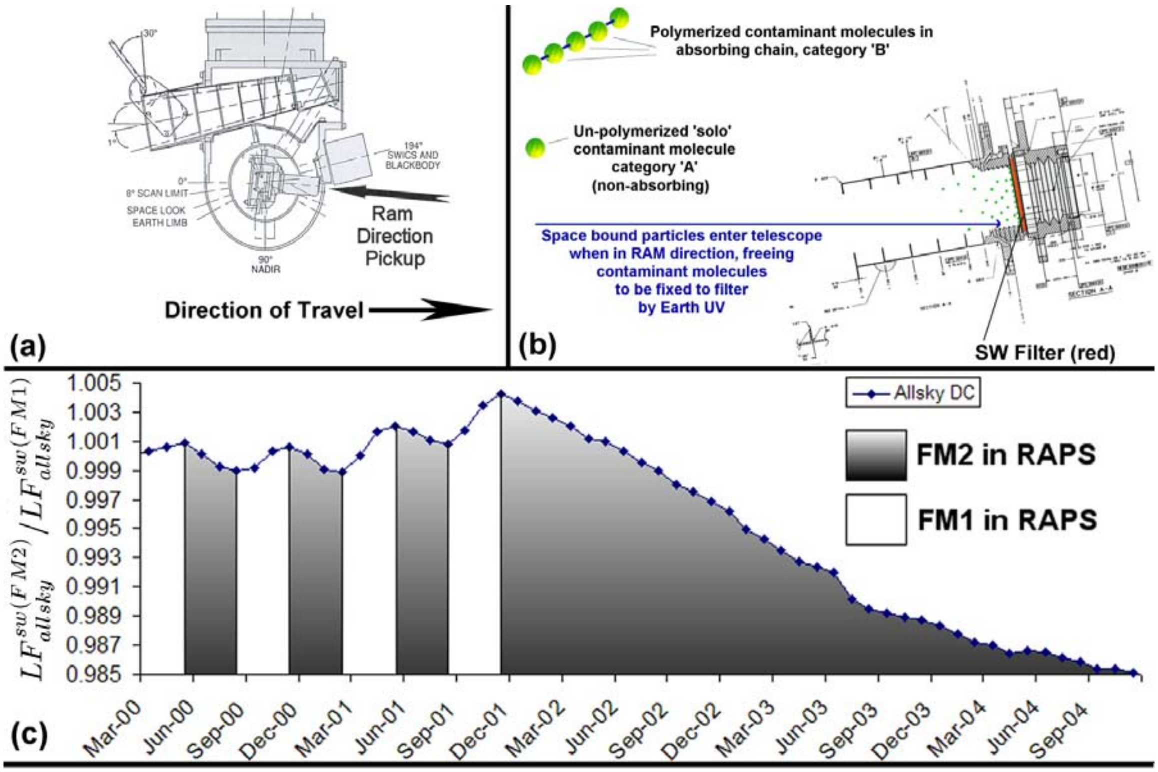

Fig 3. (a) CERES telescope exposure to the RAM direction of travel during RAPs mode. (b) Space bound particles collected when facing the RAM direction mobilize contaminant to arrive at the SW optics. (c) Ratio of simultaneous nadir footprint SW measurements made by 2 CERES units on the same platform. This clearly shows the RAPs instrument drops in response compared to its cross-track counterpart with no RAM exposure.

So severe was the effect on CERES instruments that a comprehensive model (Matthews 2006) of contaminant transmission, mobilization and polymerization was required to update the CERES spectral response and fully compensate for the effects of spectral darkening on CERES data products. In the model Eqn. 1.1 is used to estimate the increasing thickness B(t) of polymerized absorbing contaminant on the CERES optics:

$$\frac{dB(t)}{dt} = \rho\left[\int_0^t N(\xi)d\xi - B(t)\right] + \beta.N(t) \qquad (1.1)$$

N(t) is amount of contaminant mobilized to the optics during each month operating in RAPs mode (Fig 4(a)) and acts as a forcing function in Eqn. 1.1. β is the fraction of the arriving contaminant that is already polymerized (category 'B', Fig 3(b)). The remaining fraction 1-β of un-absorbing category 'A' molecules arrives and continues to be polymerized at a fractional rate of ρ per month. Hence even in cross-track mode where no contaminant arrives (i.e. N(t)=0) the thickness of absorbing chains continues to increase as category A molecules turn to category B (Fig (4(b)).

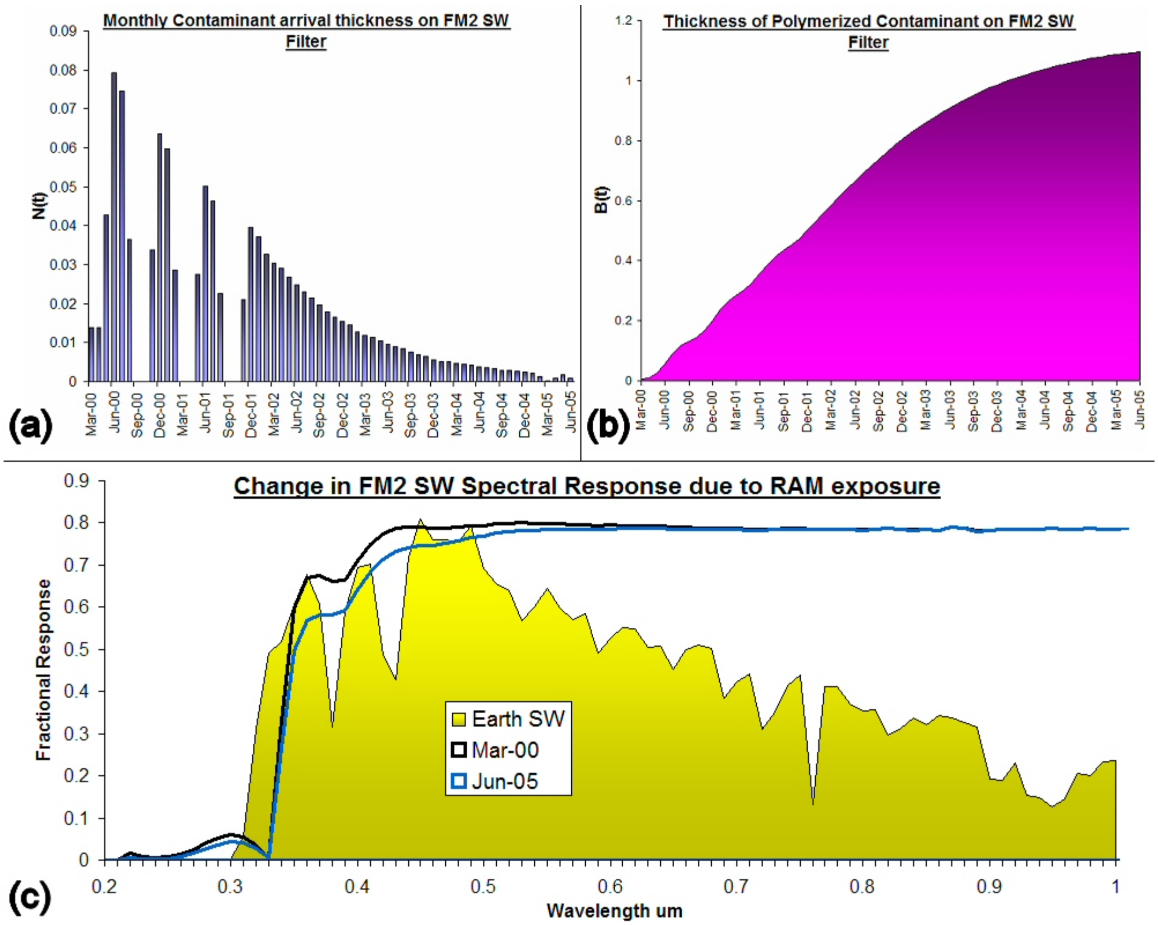

Fig 4. (a) Estimated thickness of contaminant arriving each month on FM2 SW optics. (b) Estimated monthly thickness of polymerized absorbing contaminant on FM2 SW optics. (c) Change in FM2 SW spectral response due to contaminant mobilized during RAM exposure.

Fig 4(c) shows the estimated change in the FM2 spectral response after 5 years of intermittent exposure to RAM direction and continuous polymerization of contaminant present on the optics. This represents a 2.5% drop in optical response to a typical Earth SW scene and a 4.5% drop in response for a blue Earth scene such as clear ocean. Unchecked, this would result in an artificial 6W/m^2 drop in measurements of outgoing SW flux from the Earth.

3. IMPLICATIONS FOR EarthCARE

Following the discovery of spectral darkening of the CERES optics, all existing and future scanning units are prevented from ever looking in the forward direction. The proposed EarthCARE BroadBand Radiometer (BBR) requires one of its 3 telescope systems to permanently view forwards at an angle of 55° (Fig 5). Hence the effects of RAM exposure on the forward looking telescope should be considered in the design process to prevent degradation at a far more rapid rate than for the nadir and aft viewing counterparts.

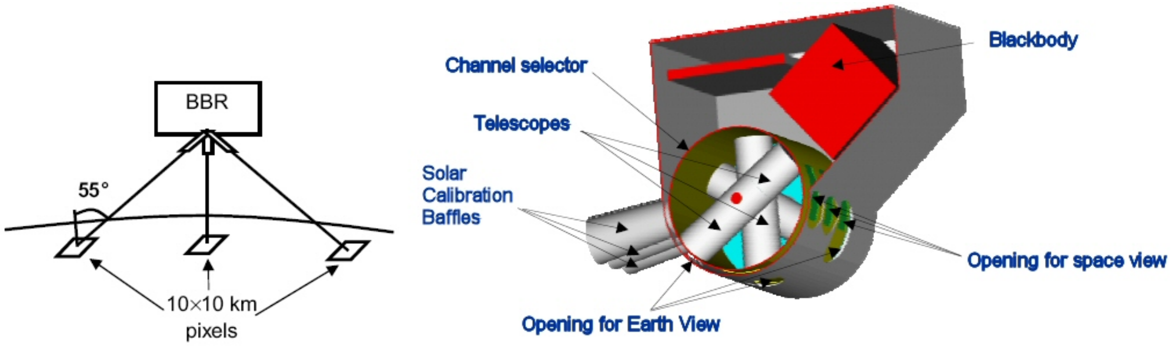

Fig 5. The EarthCARE BroadBand Radiometer (BBR)

The spectral nature of the darkening seen on the RAM exposed FM2 instrument (Fig 4(c)) is most difficult to characterize accurately. Solar diffusers can themselves be subject to the same spectral darkening as the CERES optics from both ground and in-flight contamination, rendering them useless in monitoring changes in SW response (Matthews 2006). Furthermore, even a perfectly stable solar diffuser provides no information on the coloration of the spectral darkening occurring on the Earth viewing optics. It was only possible to derive the changes to the CERES spectral response because of the proximity of two instruments on the same satellite platform operating in different modes and hence degrading at different rates (Matthews 2006). Unfortunately, such a technique would not be applicable for a solo EarthCARE instrument. It is therefore recommended that specific emphasis on contamination prevention and spectrally resolved monitoring of changes to optical throughput be made.

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